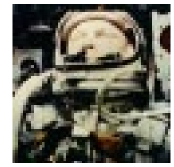


Big Things in Tiny Packages: Designing Biochips for Space

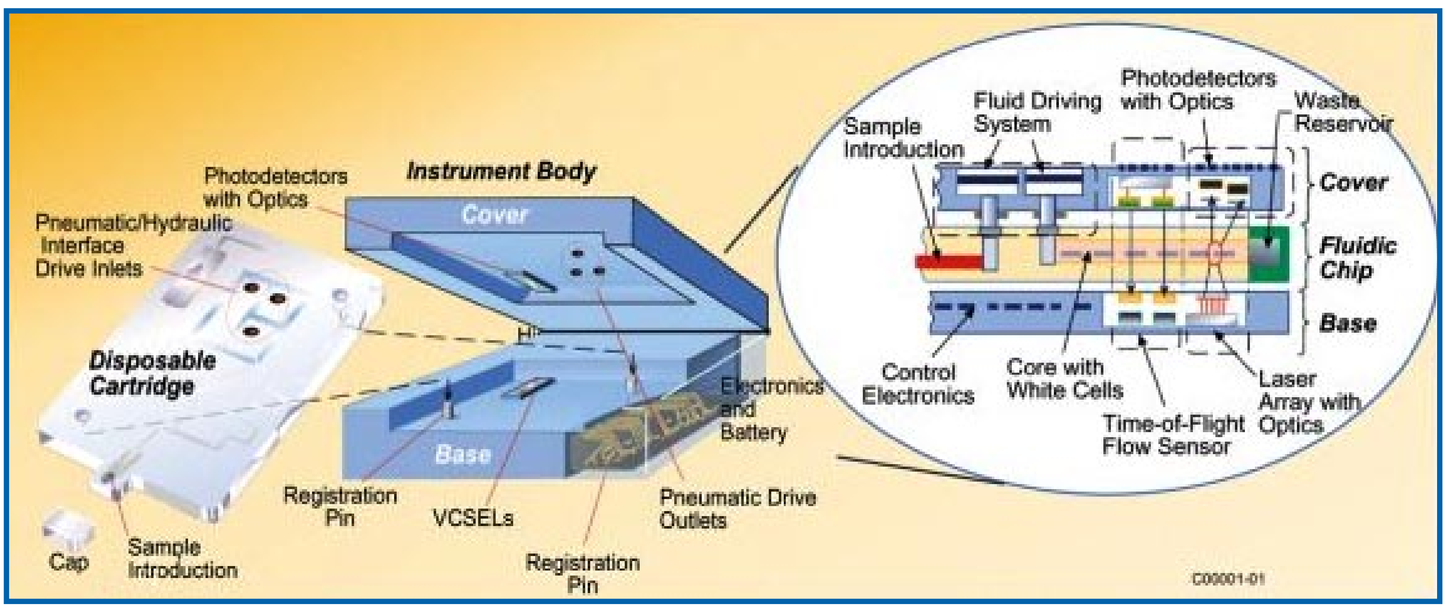
Tiny biochips, called "labs on a chip," are being developed for use in a broad array of medical diagnoses. Like a computer chip that can perform millions of mathematical operations almost simultaneously, a biochip can perform thousands of biological reactions, such as decoding genes, in a few seconds.

When space crews are operating thousands of miles from Mission Control, they have to bring the right tools with them, and they can't afford to bring spares. Because of the cost of every kilogram sent to space and scarce on-orbit resources, miniaturization has become more and more important to NASA. The smaller the size of a given instrument or experimental payload, the more instruments and experiments can be flown.

NASA is seeking miniaturization for space missions particularly in the life sciences. One vision is to bring onboard as much as possible of the diagnostic or processing capability of a state-of-the-art biotechnology laboratory and the medical instruments of an Earth hospital. Through the John Glenn Biomedical Engineering Consortium (GBEC), principal investigators Arnon Chait of Glenn Research Center (GRC) and Mohammad Kassemi of the National Center for Microgravity Research, with co-investigators Charles Panzarella (Ohio Aerospace Institute), David Jacqmin and Emily Nelson (GRC), and Marianne Zlatkowski of Case Western Reserve University are developing biochip technologies that can perform some of these functions in miniature.

A biochip is a collection of miniaturized test sites (microarrays) arranged on a solid substrate that permits many biological tests to be performed at the same time to achieve higher throughput and speed. The biochip's surface area is usually no larger than a fingernail. Like a computer chip that can perform millions of mathematical operations almost simultaneously, a biochip can perform thousands of biological reactions, such as decoding genes, in a few seconds.

New biochip technologies promise important advantages for space applications, such as reduction in size and power consumption and miniaturized diagnostic functions that enable multiple assays on the same device. In order to prepare biochip technology for widespread applications in space, the complexities of fluid physics in microgravity must be understood and incorporated into the design of the biochip. Experience with fluid physics experiments has demonstrated that a naïve porting of Earth-optimized devices to space without any special adaptations can have serious consequences.



A wearable continuous host infection monitoring platform (CHIMP)—courtesy of DARPA.

Specifically, the relative roles of surface tension physics and multiphase flows are expected to dominate in space-bound miniaturized devices. These phenomena are not easy to understand and predict without fundamental analysis tools.

The best way to produce devices that are optimized for use in the space environment is to apply advanced computer design techniques. Computer analysis tools must be able to predict the formation and motions of bubbles, cells, and other elements in microdevices in the space environment. This research aims to develop biochip designs and simulation capabilities to optimize space-bound biochips for medical and diagnostics applications. To make experiments more effective in microgravity conditions, researchers will try to elucidate fundamental space-specific physical phenomena that are common to all biochip devices intended to operate in space.

Biochip design utilizes the best of what we have learned about miniaturization and what natural forces can accomplish. Biochips rely on a miniaturized microfluidics system based on complex fluid physics to move liquids containing various reagents and samples to be analyzed to and from holding regions. Most biochips today exploit various electrokinetic phenomena such as electroosmosis and electrophoresis to move reagents and samples within the chip. Novel techniques using centrifugal forces and dielectrophoresis have also recently emerged.

Many biochips fail in practice because of the complicated, specialized nature of fluid flow through very small channels and pipes. If the channels are made larger, then gravity enters the problem in fluid flow behavior here on Earth. This makes it more difficult to anticipate how the device will really operate in space. NASA plans to rely on the data and knowledge gained with larger fluid systems in experiments in space, where gravity did not contaminate the results. Remarkably, the knowledge gained from space in larger scale experiments can be applied directly to the small biochips to be used either on Earth or in space. By incorporating the latest fluid physics findings about capillarity, multiphase flow, and surface science, the biochip simulation platform will be used to enable production of devices that are optimized for space and ground-based biomedical applications.

Benefits on Earth

This consortium project is fundamentally interdisciplinary in nature. Biochips are essential elements of the exploding field of "labs on a chip" planned to be used for a broad array of medical diagnoses. This project directly supports terrestrial work on the development of biochips by using the information gained in larger scale experiments from space (as described above) and applying that knowledge to the design of devices used on Earth. To get from here to there (and back), the project will expand the computational capability of the simulation tools used to design biochips here on Earth.

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